Nanotubes, flattened, create carbon films

R. Colin Johnson

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Portland, Ore. -- Researchers at the Georgia Institute of Technology, in cooperation with the Centre National de la Recherche Scientifique (CNRS) in France, have flattened out carbon nanotubes into monofilms to create a new material they call "epitaxial graphene." The material has low-resistance electrodes, full lithographic compatibility and the ability to control the wave properties of electrons as well as their conventional electronic properties.

Carbon nanotubes measure only 1.5 nanometers in diameter. When fabricated as the channel of an otherwise silicon transistor, nanotubes provide an avenue that traverses the semiconductor road map all the way to atomic dimensions. Unfortunately, the vast size difference between 1.5-nm-diameter nanotubes and the 65-nm features of state-of-the-art semiconductors today makes their electrodes overly ohmic, their lithography troublesome and their suceptibility to conventional pitfalls like parasitic capacitance acute.

The new material "will be easily integrated with lithographic silicon chip-processing steps, because we have the orientation of its growth under control," said Phil First, a professor at Georgia Institute of Technology. "So far we have demonstrated features as small as 80 nm; a conventional field-effect transistor made from graphene; and a quantum interference device that manipulates electrons as waves."

The research was performed by First and fellow professor Walt de Heer, along with researchers Claire Berger, Nate Brown, Edward Conrad, Zhenting Dai, Rui Feng, Phillip First, Joanna Hass, Tianbo Li, Xuebin Li, Alexei Marchenkov, James Meindl, Asmerom Ogbazghi, Thomas Orlando, Zhimin Song and Xiaosong Wu of Georgia Institute of Technology; and Didier Mayou and Cecile Naud of CNRS.

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Carbon nanotube field-effect transistors (FETs) have already been demonstrated by IBM Corp. (see www.eetimes.com and search for article ID: 183702706), but those devices had excessive contact resistance between their conventional metal electrodes and the tiny underlying nanotubes. In addition, the ballistic electron transport of the nanotubes was confined to the transistor's channel and parasitic capacitance slowed down its operation. The Georgia Institute of Technology researchers believe that their graphene films will solve all those problems.

"It is possible to create FETs with graphene, and we have demonstrated one. However, ultimately it appears that the coherence length for electrons in these materials is so long that we can make interference-type devices that use electron-wave interference in a manner similar to the way light-based devices today use optical interference and diffraction," said First. "The effective mass of carriers in graphene is essentially zero, resulting in the remarkable electronic properties of graphene--namely, that its energy vs. electron momentum is linear. In other words, energy and momentum are proportional to one another, unlike semiconductor carriers today.

"Carriers in graphene act more like neutrinos or light waves, which have no effective mass."

Graphene has the same pure carbon crystalline lattice structure as nanotubes. But when it is flattened out, it forms a single atomic monolayer of pure carbon above a single-crystal silicon substrate.

The process begins with a silicon carbide wafer, heated in a high vacuum to evaporate the silicon atoms from the top layer, leaving behind a monolayer of pure carbon in the graphene'scrystalline lattice.

"Graphene solves the problem of how do you put billions of carbon-based transistors in a circuit," said First. "Graphene offers a good, scalable way to do that. We have shown that graphene can be processed lithographically using the same tools used to make silicon chips, while preserving its remarkable qualities."

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